Motivation

- Enhance fidelity of Radar system performance analysis
- Signal power spectral density (PSD) analysis
- PSD Examples
- Signal power transfer ratio computation
- Radar transmit signal spectrum filters
- Radar receive front end filters
Motivation

• Jammer filtering
• Adaptive nulling phased array antenna modeling
• Radar development direction
• All analysis and graphs have been produced with STKv8.1
Review of STK/Radar Developments

• Dynamic Radar Jamming Analysis
  – Dynamic geometric analysis
  – Object attitude dynamics
  – Frequency, Doppler shift and Bandwidth overlap analysis
  – Jamming power computation as seen by the Radar
  – Radar performance analysis under jamming
  – Uniform power distribution model used
Current STK/Radar Developments

• Protection of radar from jammers
• Review jammer signal types
• Interaction of jammer signals with the radar signals reflected from targets
• Compute true jammer power as seen by the radar
• How to reduce the jammer power into the radar receiver
  – Spectrum Filters
  – Adaptive nulling phased array antennas
Power Spectral Density (PSD)

- Relationship between the signal power and the bandwidth (viewed in frequency domain)
- The basic units are Watts/Hz
- The power of a waveform can be precisely defined
- The bandwidth usually extends to infinity and has to be defined (-3 dB or Null-to-Null bandwidth) or limited by filters
- The PSD is symmetric, i.e. PSD (f) = PSD (-f)
- Non-symmetric PSD can be engineered
Radio Detection And Ranging
Radar Equation

\[ P_r = \frac{P_t \cdot G_t L_t \cdot G_r L_r \cdot \lambda^2 \cdot L_p L_L L_x \cdot \sigma_T}{(4\pi)^3 \cdot R^4} \]

- G is Gain, L is Loss, R = Range
- Radar bandwidth is wide enough to receive all the power spread over the band.
- Target’s Radar Cross Section (RCS) may impact parts of the spectrum differently
Radar Cross Section (RCS)

- Each object has a RCS signature
- Measure of the fractional power reflected from a target
- $\sigma = \text{GCS} \times \text{reflectivity} \times \text{directivity}$
  - GCS is the Geometric cross-sectional area of the target
  - Reflectivity is the ratio of the scattered power to the incident power
  - Directivity is the ratio of the backscatter power to the total isotropic power
- Reflectivity and the directivity are functions of the frequency
Jammer Types

- Wideband, white noise
- Wideband, colored noise
- Narrowband
- Single frequency, Continuous wave (CW)
- Pulsed
- Transponders with delay
Continuous Wave Radar signal

- Ideal carrier
  - Pure sine wave
  - Bandwidth 1Hz

- Real CW signal
  - Jitter
  - Drift
  - Significant bandwidth
CW Radar Signal Model

- PSD is modeled as a normalized Gaussian curve
- User specified RF bandwidth is used as a reference
- The power density is spread over the RF bandwidth as a ±6 sigma Gaussian curve
Gaussian PSD Model

\[ \sigma_{\text{Limit}} = \pm 6 \]

\[ x = \frac{Bw}{2 \cdot \sigma_{\text{Limit}}} \]

\[ PSD(f) = e^{-\left\{ \frac{f^2}{2 \cdot x^2} \right\}} \]
CW Radar PSD
Pulsed Carrier Radar Signal

- $\tau$ is the pulse width
- $T$ is the pulse period
- $NT$ is total signal duration
Pulsed Carrier Radar Signal

• Radar signal is transmitted as series of pulses
• Pulse width “tau” determines the spread of the spectrum
• Pulse repetition period “T”
  – Pulse repetition Frequency (PRF) = 1 / T
• Total signal duration is NT
  – N is the number of pulses
Pulsed Radar Signal PSD Model

\[ \text{Sinc}((\omega - \omega_c) \cdot \frac{NT}{2}) + \sum_{n=1}^{\infty} \text{Sinc}(n \cdot \omega_0 \cdot \frac{\tau}{2}) \cdot \bullet \]

\[ [\text{Sinc}(\omega - \omega_c + n\omega_0) \cdot \frac{NT}{2} + \text{Sinc}(\omega - \omega_c - n\omega_0) \cdot \frac{NT}{2}] \]
Pulsed Radar Signal Model cont’d…

\[ \begin{align*} 
\omega_0 &= 2 \cdot \pi \cdot f_r = \frac{2 \cdot \pi}{T} \\
\omega_c &= 2 \cdot \pi \cdot f_c \\
T &= \text{pulseperiod} \\
\tau &= \text{pulsewidth} \\
NT &= \text{SignalDuration} 
\end{align*} \]
Pulsed Radar Signal PSD
Pulsed Radar Signal Model

\[ Sinc\left((\omega - \omega_c) \cdot \frac{NT}{2}\right) + \sum_{n=1}^{\infty} Sinc\left(n \cdot \omega_0 \cdot \frac{\tau}{2}\right) \cdot \]

\[ \left[ Sinc\left(\omega - \omega_c + n\omega_0\right) \cdot \frac{NT}{2} + Sinc\left(\omega - \omega_c - n\omega_0\right) \cdot \frac{NT}{2} \right] \]
Pulsed Radar Signal PSD
Spectrum Filters

- Filters change the shape of the power spectrum density (PSD) curves
- Allow transmitted signal to conform to the regulation (or the allocated spectrum)
  - Bandwidth
  - Total power
  - PSD
Radar Receiver Matched Filters

- Match the receiver filter transfer function to the received signal characteristics
- Produce maximum instantaneous S/N ratio (SNR) in the presence of white noise
- Referred to as optimum filters in the SNR sense
- Perfect matching is difficult to achieve. Some degree of degradation in real system occurs
Matching Signal/Receiver Bandwidths

- Radar signal spectrum is adaptively sampled ±6 Sigma or from -15 Nulls to +15 Nulls of the spectrum band
- The received spectrum is dynamically adjusted for the Doppler shift due to the relative velocity of the Radar and the target
- Adaptive sampling matches the step size to the Radar’s transmit side bandwidth
- All signal power within the Radar LNA’s bandwidth is captured
Bandwidth Overlap Ratio

- Signal spectrum is convolved with the Radar’s front end bandwidth
- Radar bandwidth to signal PSD ratio is computed on a (0-1) normalized scale
- “0” represents no bandwidth overlap between the reflected signal and the receiver
- “1” represents the 100% of the signal power received by the receiver
Signal PSD and Matched Filtering
Radar PDet no filtering
PDet with wideband Filter
Radar PDet with Narrowband Filter
Phased Array Antennas

- Hundreds to thousands of radiating elements are combined to form the desired antenna gain pattern
- The phase, power, and frequency of the signal to each element is computed and controlled

Patriot Phased Array Antenna (courtesy Wikipedia)
Phased Array Adaptive Nulling Antenna

• Add a spatial dimension to the signal processing to improve S/N ratio
• Adapts the gain pattern by steering the main beam in the direction of the desired signal
• Create antenna gain null patterns towards jammers
• STK models the Least Mean Squared (LMS) steepest decent adaptive nulling algorithm
Adaptive Nulling Algorithms

• LMS steepest descent
• Howells-Applebaum
• Sample Covariance Matrix Inversion
Adaptive Antenna Schematic

Array Output

Error Signal

Reference Signal
Forming a Pattern Null
Adapted Pattern

Jammer
Adaptive Nulling Phased Array
Radar Development Direction

• Radar SAR plug-in constraint
  – National Imagery Interpretability Rating Scale (NIIRS)

• Radar Search/Track plug-in constraint
  – Probability of object detection

• Radar system polarizations
  – Transmit signal polarization
  – Radar receive antenna polarization

• Target RCS polarization

• Pulse compression
Thank you very much for your time and interest

Questions?